OBMAC: an Overhearing Based MAC Protocol for Wireless Sensor Networks

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Abstract

In this paper, we propose an enhancement for medium access control (MAC) protocol by using overhearing technique that we call OBMAC (Overhearing Based MAC) in wireless sensor networks (WSNs). In this type of networks, sensors are spatially correlated and they often sense the same information and send the same information to the sink. Therefore, sensors waste energy for transmitting redundant data. Here, we want to find a method to reduce these redundant transmissions. In WSN, overhearing is often considered a cause of energy waste. However, in this paper, we want to show that overhearing is not always an energy waste. Moreover, it can be an efficient method to reduce redundant transmissions in sensor networks. Reducing the number of transmissions helps to reduce energy consumption and the transmission delay. Hence, the network lifetime can last longer and the sink receives events within shorter delays. We propose to apply our technique in IEEE 802.15.4, a recent standard for WSN. By simulation and experimentation, we prove that OBMAC overpasses IEEE 80215.4 by reducing energy consumption and transmission delay for each event.

1. Introduction

A wireless sensor network is a network composed of hundreds to thousands of communicating sensors and deployed in an area to collect environment events. In a sensor network, each node is a small sensor with a low capacity of processing, storage and energy. Sensors are often battery powered and we expect a lifetime of several months to several years. Hence, the major difference between the sensor network and the traditional wireless network is that sensors are very sensitive to energy consumption. In the future, when sensor manufacture becomes massive, sensor price will be much lower and it is preferable to change sensors rather than batteries after use.

Indeed, when sensors communicate, there is always energy waste. In [1], W. Ye et al have identified four reasons for energy waste. First, collision occurs at the destination node when two or more interfering nodes transmit a packet at the same time. This collision implies retransmitting messages and increases energy consumption. The second reason is over-hearing, where a node listens to the packets which are not destined to it. In wireless networks, a node often listens to the communications of others in order to avoid transmitting during another transmission. In addition, control messages are also a source of energy waste. Finally, idle listening is the time when a node listens to the channel to wait for a possible incoming packet. In this case, the node must switch its radio on and if there is no transmission to it, energy is wasted.

Normally, a sensor radio has 4 operating modes: transmission, reception, idle listening and sleep. MICA [2] is a typical example. Its energy consum-ption in transmission/reception/idle/sleep mode is respectively 80/30/30/0.003 mW. In most cases, energy consumption in listening mode and idle mode is approximately equal, and half of the energy used in transmission mode. On the contrary, the energy consumption in sleep mode is much lower. Hence, we should put the radio in sleep mode as much as possible. It is the main objective of many existed works for MAC layer in wireless sensor networks. However, in most cases, energy consumption in reception mode is lower than in transmission mode. Therefore, we would like to show another aspect of overhearing mode in WSNs. We want to show that overhearing is not always an energy waste, but in certain cases, it can be an efficient method to save energy.

In WSNs, sensors are often deployed randomly and redundantly to sense events. When an event occurs, many sensors collect the same information and send it to the sink. For example, in a fire detection sensor network, if there is a fire, many sensors will collect the similar temperature and send it to the sink. In this case, there are two problems. First, sensors lose energy sending redundant data. Second, since there are many transmissions at the same time, the network congestion increases, which is likely to generate more collisions in the network.

These problems prompted us to propose an enhancement for existing MAC protocols in wireless sensor networks. The main aim of our technique is to use overhearing mode in order to reduce the number of redundant communications. By doing so, we can subsequently reduce energy waste and transmission delay therefore maximizing lifespan of the network.

2. Related works

Today, research on the medium access control of wireless sensor networks is very prolific. There is a clear attempt to improve MAC protocol in order to reduce communication time between sensors. According to various characteristics, research in MAC protocol is divided into two different types: *Contention-Based* and *Contention-Free.*

Contention-free MAC is based on reservation and scheduling. Here, each node announces a time slot that they want to use to the coordinator of the network. This coordinator schedules the request and allocates to other nodes their respective time slots. In this way, a node can access the channel without colliding with others because it is the only node which can transmit during its time slot. Bluetooth [3], TRAMA [4] and LEACH [5] are examples of this type of MAC.

This technique guarantees low energy consumption because each node in the network works only in its time slot without collisions. However, the main drawback of this technique is that it does not adapt well to topology changes and is therefore non-scalable. Any addition or deletion of a node implies a time slot rescheduling for all the nodes in the cluster. Moreover, the nodes must be well synchronized among them (about several µs), which is not easy to achieve in the widely distributed and scalable environment of a sensor network.

Unlike this technique, *contention-based MAC* is a protocol where every node competes to access the channel. Before transmitting a message, a node listens to the channel to see whether there is already a transmission in the medium. If the channel is busy, it will wait for a random time and retry to detect it later. If the channel is free, it will transmit the message. Collision occurs when two or more interfering nodes observe that the channel is free at the same time and they transmit their message simultaneously. In this case, the receivers obtain a noise signal which does not contain any information and that requires a retransmission.

The most well-known example of this technique is the IEEE 802.11 protocol [6] for wireless LAN networks. Indeed, this technique works well when the communication occurs between personal computers or pocket PCs, where energy consumption is not a major concern. This protocol does not take into account methods to save energy. However, in a wireless sensor network, the devices are small sensors and very sensitive to energy consumption. Therefore, the MAC protocol of IEEE 802.11 is not suitable for sensor networks.

As stated earlier, the sensor idle mode consumes a lot of energy. Many research projects have been carried out to optimize the existing MAC methods and better adapt them to sensor networks. S-MAC [7] is considered to be the first MAC protocol proposal which tries to reduce idle time for sensors. In S-MAC, the nodes are periodically set to listen and sleep modes, where the listen time is approximately 10% of the sleep time. In listen mode, sensors exchange their schedule and control packets in order to reach an agreement between sender and receiver. A node switches to sleep mode when it does not have any messages to send or to receive, and it switches its radio on to transmit or receive messages. Hence, the sensors might save up to 90% of energy compared to the previous protocols. However, they use control packets RTS, CTS to avoid the hidden terminal problem. These control packets create a network overhead and increase energy consumption.

T-MAC [8] extends S-MAC by changing the duration of the listening time between two active periods. T-MAC also reduces the inactive time of the sensors compared to S-MAC. Hence, it is more energy efficient than S-MAC.

Several other MAC protocols like B-MAC [9], Z-MAC [10], X-MAC [11] have been proposed with the same objective to reduce the listening time of sensors and increase the throughput of the network. Authors of these proposals have shown good results in terms of energy consumption. However, they have not been standardized by any well-known organization (like IEEE) yet.

A new communication standard which is energy efficient for wireless sensor networks is proposed in IEEE 802.15.4 [12]. The IEEE 802.15.4 is responsible for standardisation of the MAC layer and the physical layer of WSNs in order to reduce energy consumption of sensors. The main idea of IEEE 802.15.4 is to reduce active time of sensors, so that sensors can sleep the maximum during their lifetime in order to save energy. Sensors synchronise between themselves so that they are active at the same time to exchange packets and they sleep at the same time in order to save energy. However, a main disadvantage of IEEE 802.15.4 is the latency of the transmission. When sensors go to the end of an active period, even if they have more data to send, they have to sleep and wait for the next period to continue the transmission.

3. OBMAC

In this section, we describe our proposal OBMAC to improve MAC layer in wireless sensor networks. OBMAC can be applied in any existing MAC protocols for WSNs. It guarantees low cost communication and low congestion in the network. We suppose several hypotheses for the context of sensor networks. First, the wireless sensor network is deployed randomly and densely in an area to detect events related to the environment: the change of temperature, moisture, pressure, vibration etc. Second, when an event occurs, many sensors detect the same information and transmit it to the access point. Therefore, sensors waste energy to transmit redundant messages. Based on these hypotheses, we present OBMAC to better adapt to MAC protocol for wireless sensor networks. OBMAC reduces energy waste by minimizing the amount of redundant communications and guarantees shorter communication delays. As there are many MAC protocols for WSNs, we propose to apply OBMAC in IEEE 802.15.4 because it is the most well-known standard for MAC protocol in WSNs.

We organize our paper as follow: we first give a brief introduction of IEEE 802.15.4 in section 3.1. Next, in section 3.2, we show how OBMAC can be applied in IEEE 802.15.4 in order to reduce energy consumption and network congestion. In section 3.3, we introduce a new concept “influential range” which is used to refine the correctness of OBMAC.

3.1. IEEE 802.15.4

3.1.1. Topology:

The standard IEEE 802.15.4 proposes 3 types of topology: star, tree and mesh. However, the star topology does not guarantee scalability of the network; the mesh topology does not guarantee low energy consumption because nodes are always active. As the tree topology guarantees a high number of nodes and low energy consumption, we focus on this topology type (Fig. 1).

In IEEE 802.15.4, sensors are divided in three categories: coordinator, full function device (FFD), reduced function device (RFD). There is only one coordinator in the network which is responsible for the management of the whole network. It can be considered to be the sink of the network. The FFD has two roles: sense events and route packets for other devices. The RFD can sense events and send them to the FFD or coordinator. However, it can not route packets for other nodes. Hence, sensors can be organised into a tree topology (Fig. 1) in order to send alerts to the coordinator. The coordinator collects and processes information sent from sensors. When there is an event in an area, every node in this area senses this event, creates an alert packet and sends this event to the sink via FFD. The FFD forwards the packet to another FFD until the packet reaches the coordinator.

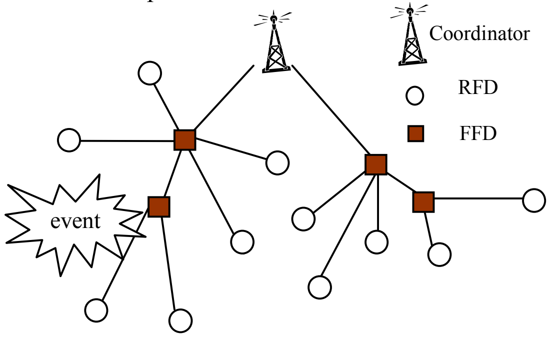

Fig. 1: Tree topology

3.1.2. Beacon mode to reduce energy consumption

In order to reduce energy consumption, the standard IEEE 802.15.4 proposes a beacon mode in MAC layer. In this mode, sensors periodically switch their radio on to communicate with others and off to save energy. However, an active sensor can not communicate with an inactive sensor. Therefore, the coordinator and FFD device periodically send a beacon packet in order to synchronize sensors. The beacon message helps sensors to know the time to wake up and to go to sleep. Moreover, it can help new sensors to join the network.

The operating time of sensor is illustrated in Fig. 2. As we observe, the operating time is divided into two parts: active and inactive. In active time, every node wakes up to transmit or receive data. They access the channel by using carrier sense multiple access (CSMA). In inactive time, every node sleeps to save energy. The beacon message is sent at the first time slot of active time in order to synchronise between sensors.

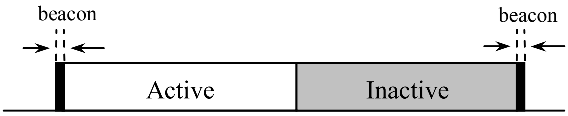

Fig. 2: Operating time of sensors in IEEE 802.15.4

3.2. An enhancement for IEEE 802.15.4

As stated earlier, IEEE 802.15.4 suffers from the overhearing problem and it is an energy waste as mentioned in [1]. In this section, we want to show a new aspect of overhearing: overhearing is not always an energy waste but in certain cases; it can be an efficient method to save energy.

Here, every node works and sleeps periodically as illustrated in Fig.2. Sensors synchronise each other by using beacon packets at the beginning of an active period. After the beacon transmission, each node competes to access the channel. It chooses a back-off time and does a carrier sense to contend the channel. If no one has transmitted till the end of its back-off time, the node changes to transmission mode and starts to transmit its packet.

The node that loses the channel switches to reception mode to listen to the transmission. It listens to the transmission in order to know whether it is the recipient or to detect the end of the transmission. If it is not the recipient, it simply drops the packet that is not destined to it. This is overhearing problem mentioned before. In a WSN, nodes in the same area probably sense the same information. Hence, all the nodes in a given area sense the same information and send the same alert to the sink. This results in redundant transmissions and energy waste. This is the reason why we want to take advantage of overhearing in order to avoid these redundant transmissions.

The principle of our approach is that *a node verifies the packet that it overheard in order to know whether it has the same information that it wants to send.* So the node does not retransmit a message which has already been sent by one of its neighbours. Before, when a node receives a packet, if it is not the recipient, it simply destroys the received packet. Now, even if it is not the recipient, it verifies whether in its message queue, there is the same information that it wants to send to the same destination (the sink). If it is the case, it simply drops its message from the queue because the same information has already been sent by one of its neighbours. If the overhearing sensor finds that the packet that it has heard is not similar to its packet, it simply destroys the overheard packet and tries to send its packet later.

By using OBMAC, we diminish the number of transmissions, thus the energy consumption is reduced and the network has a longer lifetime. Besides, nodes can reduce the transmission delay for each event. Each event in an area is detected by many nodes. In the normal case, each node sends an alert to the sink, the delay for the event is the total delay to receive the last packet. By using our technique, we reduce the number of transmissions; the transmission delay for each event will be also reduced. Moreover, we only reduce redundant transmissions but we do not drop useful transmissions.

Fig. 3 illustrates a communication between 3 interfering nodes: 2 RFD and 1 FFD. At first, the FFD sends beacon message to synchronise between sensors. Suppose that all of RFD have data to send to the sink about an event. They use carrier sense (CS) and go to contention period to access the channel. The RFD 1 wins the channel and starts to transmit data to the FFD. The RFD 2 loses the channel, but it continues to set its radio in active to overhear the communication between RFD 1 and the FFD. After each overheard packet, RFD 2 verifies in its queue whether it has the same information to send to the same destination. If it is the case, it will destroy its own packet.

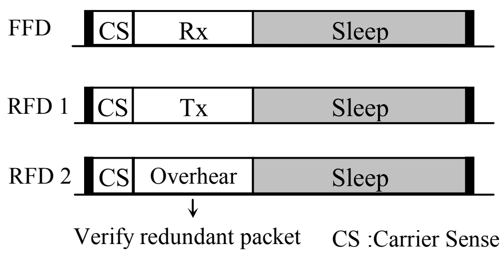

Fig. 3: Overhearing between sensors

By analyzing OBMAC, one can argue that if the data it overhears is not the same, it is an energy waste. However, in IEEE 802.15.4, nodes always overhear the communication of the others in order to know whether the channel is free. So, in 802.15.4, nodes always waste energy to overhear the communication of the others. Here, we just take advantage of this overhearing mode to reduce the number of redundant transmissions. Anyway, OBMAC never increases energy consumption in the network.

3.3. Influential range

In fact, the radio range is large: 100m in IEEE 802.11 [6], 50-70m in IEEE 802.15.4 [10]. If a wireless sensor network applies OBMAC directly, there will probably be errors and fault tolerance problems. Suppose that all nodes are interfering. When one node sends a packet, all the others can overhear this packet. First, the technique presented in section 3.2 is not fault tolerant because if there is an event, many nodes detect this event and only one alert is sent to the sink (since every interfering node overhears this alert and cancels its transmission). Second, an error might occur when there are two events with the same information which came from two different places. If nodes overhear another event and drop their own packet, it will be an error case.

So, we need to find a method to refine OBMAC in order to make it correct and fault tolerant. We define a new concept that we call *influential range (IR)*.

Definition: *Influential range* (IR) is a range where nodes are likely to observe the same information.

This range is different from the radio range, and it is always shorter than the radio range of the node. Fig. 4 illustrates the influential range and radio range. The influential range of node A is a grey circle around node A. The radio range is the bigger circle around the grey circle.

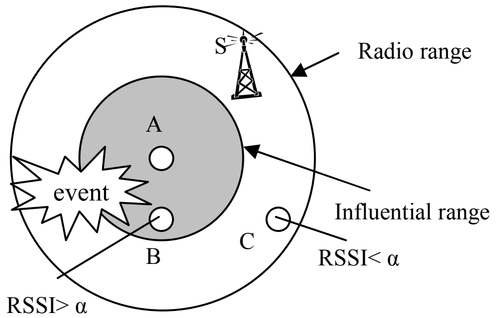

Fig. 4: Influential range

We refine the overhearing technique as follows: "*A node applies our method if and only if it is in the influential range of the transmitting node"*. Hence, only nodes in the area where the event has taken place apply our technique to verify for redundant transmissions.

Therefore, the influential range decides whether a node is set to overhearing mode. However, how can a node know if it is in the influential range? *Indeed, in our approach, the influential range of a node is defined by the transmitter node.* When the sensors communicate, the sensor which is nearer the transmitter receives a stronger signal than a more remote node. In Fig. 5, suppose node A wins the channel and transmits its packet. Because AB<AC, the signal strength received in B is stronger than in C. A node can easily obtain the received signal strength by using a circuit Received Signal Strength Indicator (RSSI). From this value, a node can estimate its distance to the transmitter.

We define a threshold α of the received signal strength to determine the influential range of a node. The IR value is considered to be the threshold α value. Again, this value is different from one application to another. It can be set by administrator by using administration tools. We will analyze the value of α in the next section. If a node receives a packet at signal strength greater than α, it knows that it is in the influential range of the transmitter. Otherwise, it is outside the influential range of the transmitter.

In Fig. 4, three nodes A, B and C want to transmit its packets to the sink. When nodes B and C have lost the channel, they hear the transmission between A and the access point. They compute the received signal strength to know whether they are in influential range. Node B finds that the received signal power is higher than the threshold α, so it knows that it is in the influential range of node A. Hence, it applies our technique to overhear the transmission and to verify with its data. Since it finds that node A sent a message to the sink with the same information that it wants to send to the sink, it removes its packet in the queue because it is redundant message. However, the node C finds that the received signal power is lower than α, it knows that it is not in the influential range of A and its alarm is likely to come from another source. So, when it overhears a packet, it simply drops this overheard packet because it is meaningless. Node C tries to transmit its packet in the queue in the next period.

4. Performance results

In this section, we will present the results of performance evaluation to prove the effectiveness of OBMAC. We use the OMNet++ simulator [13] to validate OBMAC. OMNeT++ is a public-source, component-based, modular and open-architecture simulation environment. To simulate a wireless sensor network, we use mobility framework (MF) [14], a framework to support simulations of wireless and mobile networks within OMNet++. We use the battery module [15] to simulate battery drain.

4.1. Simulation parameters

Table 1 described the simulation parameters used in our test. These simulation parameters correspond to MICA2 sensors [2]. The network is deployed randomly in a square of 500 x 500. The coordinator is placed in the center of the deployment zone. Nodes periodically send data to the coordinator.

Table 1: Simulation parameters

Deployment zone	500 x 500
Number of nodes	5 – 20
Influential range	-60 to -90 dBm
Battery Energizer Lithium AA	2900 mAh
Processor (active/sleep)	8mA / 15µA
RF transceiver (TX/ RX/ Sleep)	27mA/ 10mA/ 1µA
RF power	3mW
Receive Sensitivity	-98 dBm
Active/Sleep period	0.1 / 9.9s
Data Transfer Frequency	1pkt/10s
Simulation time	500s

4.2. Delay time

In the first evaluation, we compare the delay time between IEEE 802.11, IEEE 802.15.4 and OBMAC (Fig. 5). The horizontal axis illustrates the number of nodes. The vertical axis illustrates the total delay time of all transmissions. We can see that the IEEE 802.11 has the longest delay. The IEEE 802.15.4 has lower delay. The reason is that IEEE 802.11 uses control packets to avoid collisions. These control packets increase the transmission delay and worsen the performance of IEEE 802.11 in comparison to IEEE 802.15.4. On the contrary, OBMAC always guarantees the shortest delay. In general, the more nodes there are in the network, the more time it takes to transmit all data.

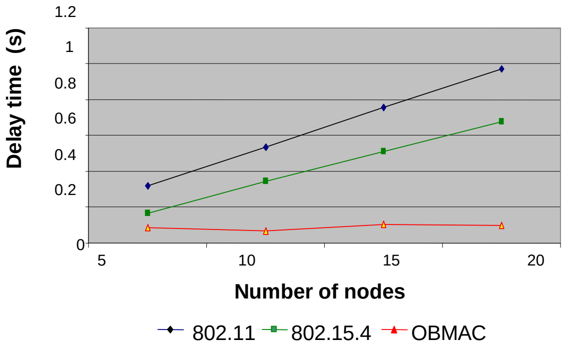

Fig. 5: Delay time with influential range = -90 dBm

By reducing redundant transmissions in OBMAC, nodes avoid transmitting useless packets and reduce transmission delays for each event. We can see that in OBMAC, the delay time is not influenced by the number of nodes. As the number of nodes increases, we increase the number of nodes in the influential range. Hence, we reduce the number of transmissions and the delay time is always approximately constant.

4.3. Energy consumption

In the second simulation test, we compare the energy consumption of our approach to that of IEEE 802.15.4. As the IEEE 802.11 does not use sleep mode to save energy, the energy consumption is very high in comparison to IEEE 802.15.4. If we illustrate the IEEE 802.11 in Fig. 6, it would be difficult to see the difference of energy consumption between IEEE 802.15.4 and OBMAC. Hence, we do not include IEEE 802.11 in Fig. 6.

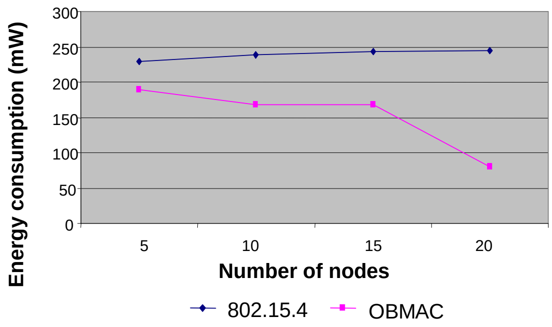

Fig. 6: Energy consumption of 802.15.4 and OBMAC

The horizontal axis illustrates the number of nodes in the network. The vertical axis illustrates the average energy consumption of all nodes in the network. With IEEE 802.15.4, all nodes send packets to the sink. As we increase the number of nodes, we increase the congestion in the network. Nodes have to wait more time to access the channel. They consume more energy. In OBMAC, as we increase the number of nodes, there will be more nodes in influential range and they will not transmit their packet because those packets are redundant packets. Hence, the energy consumption is reduced in comparison to IEEE 802.15.4.

4.4. Variation of influential range

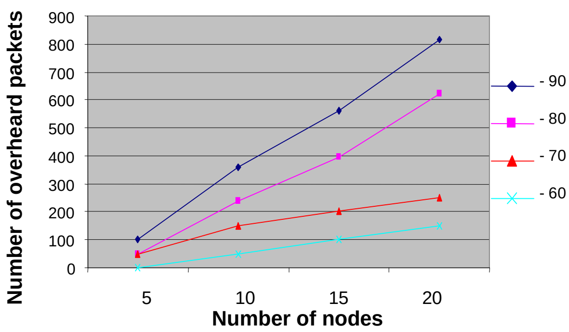

Fig. 7: Variation of IR value

In the two previous simulation results, we use the influential range IR corresponding to the threshold α = -90 dBm. Now, we simulate the network with different IR in order to see the impact of IR to the network. In Fig. 7, the horizontal axis illustrates the number of nodes. The vertical axis illustrates the number of overheard packets in the influential range. That is the total number of overheard packets in the IR by all nodes in the network. Each line in Fig. 7 corresponds to the number of overheard packets with different values of the threshold α (different IR). For each IR, as we increase the number of nodes (the network is more dense), the number of overheard packets is increased. In fact, the more overheard packets there are, the more energy we can save. So the more network is dense, the more nodes can save energy. In the case that we use the same number of nodes, if we choose the smaller threshold α, the influential range is larger. Hence, nodes receive more overheard packets in their influential range, thus the more we reduce the threshold α, the more energy we can save.

5. Conclusion

In this paper, we have shown a new approach of reducing energy consumption in WSNs based on overhearing mode. We have proven that overhearing is not always an energy waste. Otherwise, it can be an efficient method to save energy in certain scenarios. We have presented and analyzed OBMAC and apply it to IEEE 802.15.4, a very well-known MAC protocol standard for WSN. The performance results show that OBMAC overpasses the performance of IEEE 802.15.4 in terms of energy consumption and transmission delay. OBMAC works well with tree topology and offers a good latency for wireless sensor networks. In addition, OBMAC can be applied into almost all existing MAC protocol for WSNs. With the new notion "influential range", we guarantee the fault tolerance of the system where we drop only redundant transmissions.

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